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STUDIES OF ION BEAM GENERATION EFFICIENCY WITH REFLEX TETRODES.(U)
JAN 78 R A MAHAFFEY, J A PASOUR, J GOLDEN
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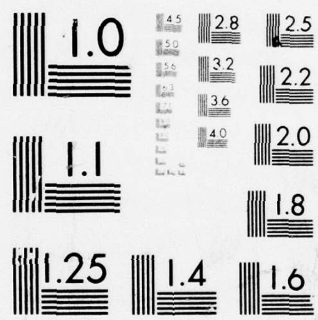

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Studies of Ion Beam Generation Efficiency With Reflex Tetrodes

R. A. MAHAFFEY, J. A. PASOUR, J. GOLDEN and C. A. KAPETANAKOS

Experimental Plasma Physics Branch
Plasma Physics Division

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The unidirectionality of the ion current in a reflex tetrode has as a result the efficient generation of pulsed, ion beams. In this paper, experimental results are reported on the dependence of the ion generation efficiency, in a reflex tetrode, upon the applied voltage, total current, anode-anode and anode-cathode separations and applied magnetic field.

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STUDIES OF ION BEAM GENERATION EFFICIENCY WITH REFLEX TETRODES

I. INTRODUCTION

Recently, low inductance, coaxial reflex triodes have been used on the Gamble II accelerator at NRL to produce proton beams with currents in excess of 200 kA[1]. Interest in the generation of intense ion beams has been stimulated primarily by their potential applications. These applications include the production of field-reversed ion rings[2], inertial confinement fusion[3], laser excitation[4], hybrid reactors[5], and plasma heating[6].

Among the various ion sources presently available, the reflex triode[1,7] has several attractive features. Reflex triodes can operate over a wide range of applied axial magnetic field and the ion current produced by a reflex triode can be considerably higher than that predicted for bipolar flow. The reflex triode has the undesirable feature, however, that about one half of the ion current flows toward the real cathode and is unusable. Under ideal conditions, therefore, the maximum efficiency of a reflex triode cannot exceed 50%. In practice, the efficiency of reflex triodes is $\leqslant$ 30%.

Various attempts have been made to increase the efficiency of reflex triodes. These include attempts to suppress the backward flowing ion current by using a compound anode[8,9] and to delay the impedance collapse[8] by using an anode that is radially displaced from the cathode. These attempts have resulted in only modest increases in efficiency and poor shot-to-shot reproducibility.

Recently, however, a new configuration[10] (called the reflex tetrode) has been developed. This device (obtained by adding a second anode to a reflex triode) preserves the advantages of a reflex triode while reducing the wasted ion current which flows toward the real cathode to $\leqslant$ 2%. This reduction in backward streaming ion current in a reflex tetrode[10] results in a large improvement in proton production efficiency. The maximum efficiency under ideal conditions

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may approach 100%. In addition, impedance collapse is reduced since there are few backstreaming ions to enhance the cathode emission.

This letter reports on various factors which can influence the proton generation efficiency in reflex tetrodes, including applied voltage, total current, anode-anode separation, anode thickness, anode-cathode gap, and the applied axial magnetic field.

II. EXPERIMENT

A schematic of the reflex tetrode experiment is shown in Fig. 1. A 5-cm diam. graphite cathode which is at ground potential is located a distance A_1-K from the first anode, A_1. This anode foil is either a 2-μm-thick polycarbonate (kimfol) or a 6 or 12-μm-thick aluminized mylar foil. The second anode, A_2, is placed a distance A_1-A_2 from A_1 toward the virtual cathode and is made of 13-μm-thick polyethylene foil. The primary source of protons is the polyethylene anode (A_2) as aluminized mylar or kimfol anodes have been observed to be poor sources of protons in previous reflex triode experiments.[11] Anodes A_1 and A_2 are at the same electrical potential. The hypothesized electric potential of this configuration is shown in Fig. 1. This potential results in the suppression of the ion flow in the A_1-K gap. The anodes are mounted on the edges of a 12.7 cm I.D. aluminum ring. The ring is connected to the Seven Ohm Line (SOL) generator which is operated in positive polarity. The output voltage pulse of this generator has an amplitude U_o and a duration of $\approx$ 50 nsec (FWHM). The experiments are performed with an applied axial magnetic field B_o.

The number of protons emitted in either axial direction is determined by nuclear activation techniques[12]. Thick carbon (C) or boron nitride (BN) targets are placed $\approx$ 7 cm from A_2 to determine the number of forward-directed protons. The number of back-directed protons is determined by measuring the

activity induced in the graphite cathode and on BN or carbon targets placed around the cathode. In cases where the proton flux is intense enough to cause substantial target blow off[12], a 33% transparent screen is placed in front of the target to reduce the number of protons striking the target.

Since nuclear activation gives only the time integrated proton yield, the proton current is inferred from the total yield together with the duration of the proton pulse. The duration of the proton pulse is assumed to be equal to the time interval from plasma formation until the diode voltage drops below the threshold for target activation (277 kV for the $^{14}N(p,\gamma)^{15}O$ reaction on BN, 430 kV for the $^{12}C(p,\gamma)^{13}N$ reaction on graphite). To determine the proton generation efficiency ϵ, the resulting average proton current is divided by the average value of the total current during this time (as measured with a resistive shunt in the outer conductor of the SOL generator).

The proton generation efficiency is graphed versus the average value of the shunt current for two values of the applied voltage in Figure 2. For these experiments, $B_o \simeq 5.6$ kG, A_1-K $\simeq 1.7$ cm, A_1 is 6-μm-thick aluminized mylar and A_1-$A_2 \simeq 0.5$ cm. As seen, for constant voltage, ϵ increases with the shunt current I. For constant current, ϵ increases with decreasing voltage. In addition, the proton generation efficiency for reflex triodes is approximately one half the efficiency of reflex tetrodes. The observed scaling, $\epsilon \sim I/U_o$, has also been observed for reflex triodes[13]. This scaling is apparently the result of the virtual cathode dependence on the system parameters. That is, the larger the number of oscillating electrons N_{osc} in the device ($N_{osc} \sim I$) or the lower the applied voltage (energy of electrons) the closer the virtual cathode forms to A_2. A smaller distance between the virtual cathode and the anode results in a larger electric field on the side of A_2 toward the virtual cathode.

Thus, the observed dependance $\epsilon \sim I/U_o$ is expected.

Figure 3 shows schematically the dependence of the electric potential on the A_1-A_2 gap. If A_1-A_2 is too small (Fig. 3a), the tetrode's electric potential is similar to a reflex triode and little improvement over reflex triode operation is expected. If A_1-A_2 is made too large (Fig. 3c), it is possible that a virtual cathode is formed between the two anodes and thus electrons are unable to reach A_2. Therefore, an optimum A_1-A_2 gap is likely. Experimentally, this is found to be the case as is illustrated in Fig. 4. In these experiments, $B_o \simeq 5.6$ kG, A_1-K $\simeq 1.7$ cm, A_1 is 6-μm-thick aluminized mylar, and $U_o \simeq 490$ kV. Of the three A_1-A_2 gaps investigated, it is found that the tetrode with A_1-$A_2 \simeq 0.5$ cm has slightly better efficiency than the tetrode with A_1-$A_2 \simeq$ 1.1 cm and much better efficiency than the tetrode with A_1-$A_2 \simeq 0.2$ cm. In fact, when A_1-$A_2 \simeq 0.2$ cm, ϵ is less than for a triode with A-K $\simeq 2.3$ cm with a 13-μm-thick polyethylene anode. The reason for the low efficiency of the A_1-$A_2 \simeq 0.2$ cm tetrode is that the electric potential is quite similar to that of a reflex triode, but now the total anode foil thickness is 19 μm. The effect of anode foil thickness on proton generation in a reflex triode has been previously reported [14]. It was observed that when the anode foil thickness was increased from 13-μm to 19-μm that the proton production decreased about 15%. This is approximately the difference in efficiency between the reflex triode and reflex tetrode with A_1-$A_2 \simeq 0.2$ cm seen in Fig. 4.

With a 2-μm-thick A_1 foil (whose thickness is small compared to the 8-μm range of 0.5 MeV protons), no radioactivity from backstreaming protons is detected on the cathode nor on BN targets placed around the cathode. Thus, the unidirectionality of the proton current is

evidently due solely to the electric potential distribution and not to stopping by A_1. The effect of varying the thickness of A_1 is shown in Fig. 5. The efficiency of tetrodes with 2-μm or 6-μm-thick A_1's is approximately the same, but the efficiency of a tetrode with 13-μm-thick A_1 is reduced by about 30%. This is due to the reduced number of electron transits which result when the total anode thickness is 25-μm instead of 19-μm or 15-μm. The two smaller anode thicknesses have been found to result in approximately the same number of protons emitted in earlier reflex triode studies.[14]

In the range $2.7 \text{ kG} \leqslant B_o \leqslant 7.6 \text{ kG}$ operation of the reflex tetrode is found to be relatively independent of applied axial magnetic field. When $B_o \sim 0$, however, proton generation efficiency is greatly reduced. This is attributed to electron losses and to two-dimensional effects associated with self-magnetic fields. These effects have been observed in reflex triode experiments.[1] In addition, the efficiency of the tetrode is found to be insensitive to the range $0.9 \text{ cm} \leqslant A_1\text{-K} \leqslant 1.9 \text{ cm}$.

III. *SUMMARY AND CONCLUSION*

The reflex tetrode is a device which resembles the reflex triode but includes a second anode that modifies the electric potential. Under proper operating conditions $\gtrsim 98\%$ of the protons produced in the tetrode flow toward the virtual cathode and out of the device. Peak ion currents in excess of 10 kA (0.5 kA/cm^2) with $\approx 10^{15}$ protons have been detected on SOL. Impedance collapse in the tetrode is greatly reduced since there are very few backstreaming ions to enhance the cathode emission. Thus, a smaller A_2-K gap can be used in the tetrode configuration than in the triode configuration. Proton generation efficiencies greater than 55% have been obtained, and it is observed that the efficiency is proportional to I/U_o. The proton production efficiency for

reflex tetrodes is observed to be approximately twice the efficiency of reflex triodes under similar operating conditions.

In order to optimize reflex tetrode operation, it is necessary to have a thin A_1 and to have the proper A_1-A_2 gap. For the experiments reported here, the best A_1-A_2 gap is $\simeq 0.5$ cm, however, this value may differ at markedly different applied voltages.

It is observed that tetrode operation is not sensitive to B_o in the range 2.7 kG $\leqslant B_o \leqslant 7.6$ kG, however, $B_o = 0$ results in poor operation of the device. In addition, variation in the anode-cathode gap results in little change in tetrode operation.

Experiments with small diameter cathodes (diam. $\simeq 1.8$ cm) with average electron current density as high as 2.5 kA/cm^2 indicate that reflex tetrodes can operate with high efficiency at the power level of the Gamble II generator. Therefore, usable proton currents in excess of 400 kA may be produced by converting the coaxial reflex triodes[1] used on the NRL Gamble II generator to coaxial reflex tetrodes.

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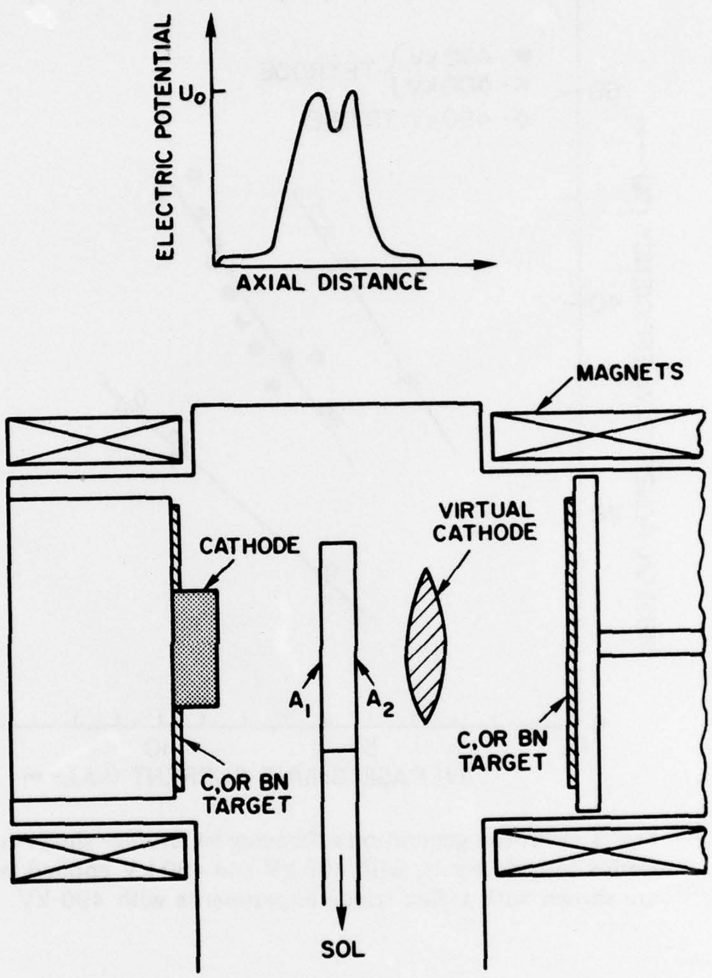

Fig. 1 — Schematic of the reflex tetrode experiment

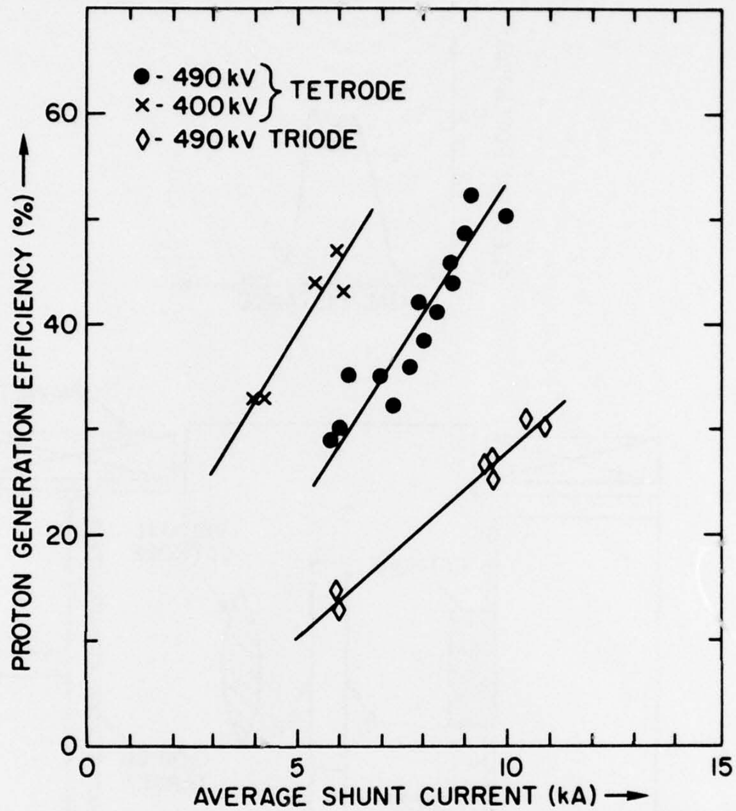

Fig. 2 — Proton generation efficiency vs. average shunt current. Reflex tetrode results with 400 kV and 490 kV applied voltages are shown with reflex triode experiments with 490 kV.

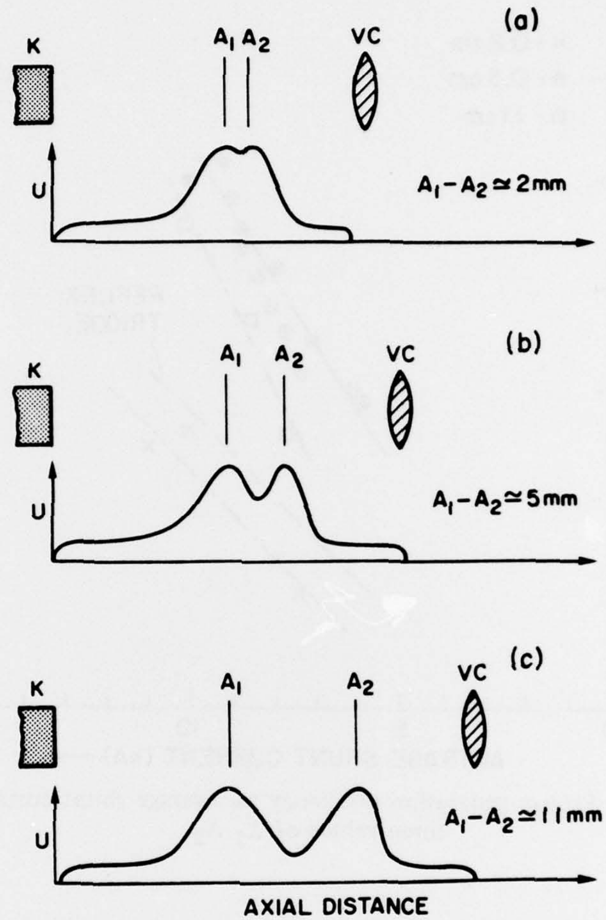

Fig. 3 — Variation of the hypothesized electric potential as the A_1-A_2 gap is changed

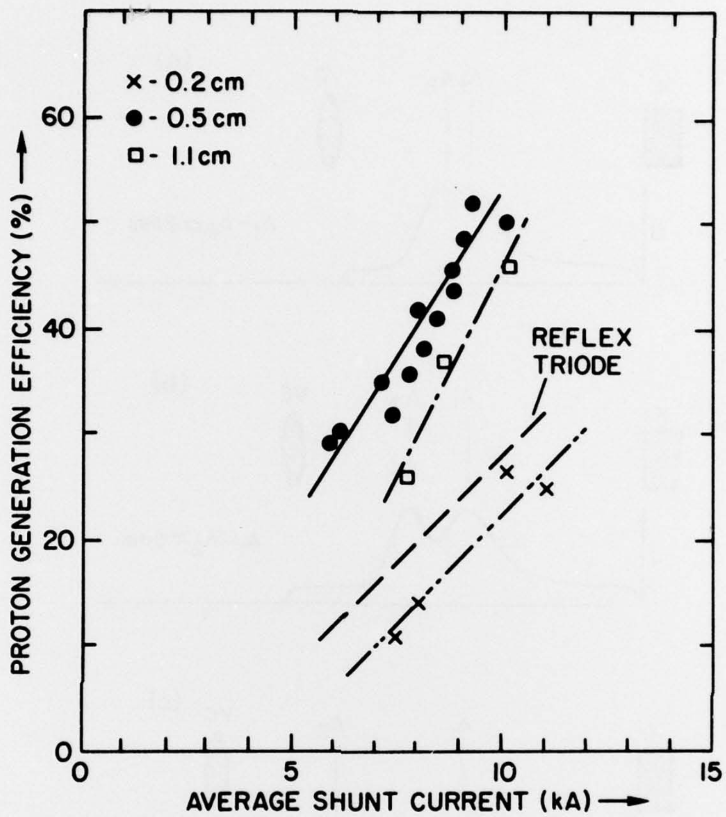

Fig. 4 — Proton generation efficiency vs. average shunt current for three values of A_1-A_2

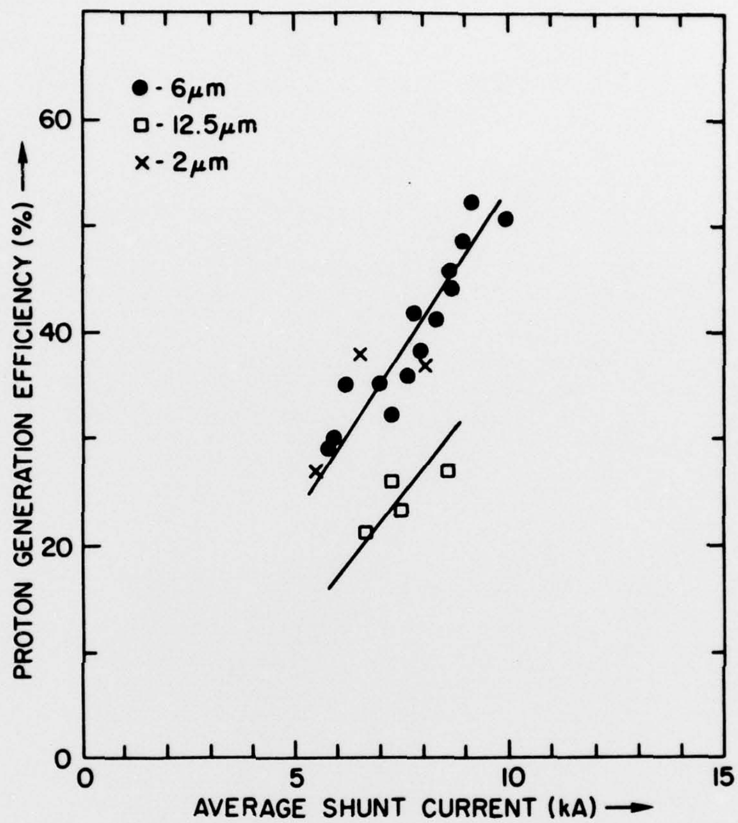

Fig. 5 — Proton generation efficiency vs. average shunt current for three thicknesses of A_1